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Immersive teleoperation of a robot arm using electro-tactile feedback

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Abstract

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Keywords

feedback, teleoperation, immersive, robot, arm, electro, tactile

Disciplines

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Immersive Teleoperation of a Robot Arm Using Electro-tactile Feedback

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Abstract—**Teleoperation can allow an operator to control a robot remotely in inaccessible and hostile places. To achieve more dexterous control of a tele-operated robot some researchers are developing user interfaces equipped with vision and tactile feedback. 3D visual perception and tactile feedback can also assist the operator to feel immersed in the robot's environment and embodied within the robot to some extent. Most existing tactile feedback systems use electro-mechanical actuators and linkages. However, these systems are complex, cumbersome and consequently make it difficult for the operator feel embodied within the robot. To improve on these drawbacks, this paper introduces an immersive teleoperation system comprised of a 3D stereo vision head set combined with an electro-tactile feedback system. Our electro-tactile feedback system is compact, non-mechanical and versatile. Experimental results are provided which show how this form of immersive 3D perception and tactile feedback system can enable the user to achieve more dexterous control of a robot arm by enabling the operator to effectively see what robot sees and experience what the robot feels while performing work with the robot.**

Keywords-, Teleoperation, immersive, tactile feedback, electro-tactile feedback.

I. INTRODUCTION

Teleoperation can enable an operator to control a robot remotely in a hazardous environments or inaccessible places. When combined with force or tactile feedback, interactions with remote objects and the environment can be facilitated to some extent. For example, [1] devised a teleoperation system that can not only enable humans to interact with the environment and objects from a far, but also enable the operator's motion and force feedback to be scaled to achieve smaller or bigger actions. There are various teleoperation applications. For example, bomb disposal [2], dangerous waste removal [3], mining equipment [4], underwater preservation [5], space missions [6] and tele-surgery [7].

Two important objectives to make teleoperation work better is embodiment, within the robot, and immersion, in remote environment, as explained by [8] and [9]. As teleoperation finds more applications, embodiment and immersion is becoming increasingly required in order to perform work that is difficult to perform remotely, as explained by [10].

Some researchers, like [11] define embodiment as being present in a virtual environment or virtual agent (or robot). Furthermore, [12] consider that the experience of using and/or having a body of any type is a form of embodiment. Immersion is defined as a process that creates an equivalent experience to a human presence in the actual remote environment, see [9].

Embodiment occurs when the operator experiences similar perception and sensations as the robot experiences from feedback, as explained by [13]. To achieve embodiment, both perception and sensory concepts must be incorporated into the teleoperation system. For example, sense of location, sense of agency and sense of body ownership.

The sense of location is the sense or experience of being in an environment within a robot or agent body, as explained by [14]. The sense of agency refers to the sense of controlling a robot or agent body, see [12]. Finally, the sense of body ownership refers to the sensations or feelings derived from the robot or agent body and its interactions with the environment, as explained by [15].

To achieve embodiment and immersion, a teleoperation system must have a suitable user interface equipped with multi-sensory feedback. Most existing teleoperation systems endeavor to achieve this with vision combined with haptic or force feedback, see [16]. However, delivering haptic or force feedback with the use of electro-mechanical actuators and linkages can be cumbersome and complex. This can make it difficult for the operator to ignore the feedback devices fitted to the operator's arms, fingers, etc. and achieve a sense of embodiment within the robot and immersion in the robot's environment.

To overcome some of the limitations of electro-mechanical feedback devices, this paper introduces an immersive teleoperation system comprised of a 3D stereo vision head set combined with electro-tactile feedback. Our electro-tactile feedback system is compact, non-mechanical, versatile, easy for the operator to fit and provides a wide range of sensations.

The paper is organized as follows: section II provides a brief overview of previous studies on visual and haptic feedback systems for controlling a robot via teleoperation. In Section III details of our 3D electro-tactile teleoperation system are presented. Experimental results are provided in Section IV. We shows how this form of immersive 3D perception, combined with electro-tactile feedback, can enable the user to achieve more dexterous control of a robot arm by enabling the operator to effectively see what robot sees and experience what the robot feels while performing work with the robot. Finally concluding remarks are provided in Section V.

II. BACKGROUND

The concept of embodiment is shown in Polanyi's blind person and the rubber hand illusion (RHI), see [17] and [18]. Polanyi also proposed that when a blind person uses a white cane to perceive their surroundings, the white cane actually becomes like part of the blind person's body. In the RHI experiment, a rubber hand is placed where it can be seen by the participant and the participant's real hand is placed out of view. Both the real and rubber hand are then caressed by the supervisor giving the participant the illusion that the rubber hand they see is the hand delivering the sensations. The rubber hand is then struck with a mallet causing much alarm to the participant due to the rubber hand being perceived their own hand.

Likewise, achieving a sense of robot embodiment can be achieved if adequate perception and sensations from the robot are delivered to the operator so that the operator feels immersed in the robot's environment. Using a joystick to control a robot remotely and immersive visual feedback can provide the illusion of embodiment to some extent, as explained in [19] and [20]. Furthermore, the sense of body location and the sense of agency can also be achieved by such teleoperation system with prolonged use.

However, to achieve a more immersive user experience, stereoscopic vision feedback is needed. Stereoscopic vision feedback can also provide more depth information on the robot's environment enabling the operator to interact with the objects in the environment more effectively, see [21] and [22]. The use of a head mount display (HMD) connected to stereo cameras can also improve the operator's 3D perception of the robot's environment and provide better agility and efficiency; see [23].

Haptic feedback can also be added to a robot tele-operator system to enhance the sense of body ownership and the level of immersive feeling. Haptic feedback can have various forms and is defined as feedback information transmitted to the operator's skin. For example, heat feedback [24], vibration feedback [25], force feedback [26] and electric feedback [27].

In [7] a tele-surgery application comprised of a teleoperation system with force feedback has been shown to produce positive results by making the operator more aware of the surgical instruments used in this system. In [28], haptic feedback for controlling a robot in assembly tasks has been shown to improve the speed and interactivity of assembly tasks. Similar result using virtual reality (VR) technology and haptic feedback has been achieved in VR environments, see [29].

However, these haptic feedback system for tele-operation are mostly application specific, complex and expensive, particularly if the feedback is delivered to the operator via actuators and mechanical linkages. For example, pulleys attached to weights to effect forces between the operator's waist and hand was used to obtain information about the position of a robot arm in [26]. In other research, a servo motors were used for "tapper", "dragger", "squeezer" and "twister" type haptic feedbacks.

Vibration has also been used as haptic feedback for performing various robotic tasks. For example, [25] used a combination of vibro-tactile and mechanical torque feedback to control a robot arm. Here, a belt is connected to the operator's arm to effect force feedback from the robot arm to the operator. Furthermore, six vibro-tactile feedbacks were used for providing information about the profile of objects surrounding the robot's gripper.

Because all these systems involve mechanical actuator, they can be inconvenient for the operator to wear and can also make it difficult the operator to move around. Moreover, the operator becomes increasingly aware of the feedback equipment attached to the operator's body making it difficult to achieve embodiment within the robot and immersion in the environment, see [30]. Furthermore, vibration actuators (i.e. tactors) generally have a low bandwidth by being capable of vibrating only at one frequency with little or no variation in amplitude.

Electrocutaneous or electro-tactile feedback is a type of haptic feedback that uses electric current to stimulate nerves within the skin. This type of feedback system can reduce the hardware required to give sensations and information to the user because it does not use mechanical actuators or linkages. Furthermore, electro-tactile feedback can be modulated by varying both the frequency and amplitude of the electric stimulus delivered to the skin. Consequently, electro-tactile feedback can give a diverse range of sensations without desensitizing the nerves to the stimulus, as explained in [31], [27] and [32]. This makes it possible to deliver different feedback signals to the operator from different sensors attached to the robot.

In the following sections, we describe the implementation details of our teleoperation system and discuss some preliminary experimental results we have achieved which demonstrate the potential of the system.

III. ELECTRO-TACTILE FEEDBACK SYSTEM

A. *Overview*

The proposed teleoperation feedback system is comprised of a CRS A465 robot arm, as shown in Figure 1, which is equipped with an ATI F/T force sensor unit fitted to the end effector. Forces from the end effector are encoded into electric pulses of varying intensity and delivered to TENS electrodes fitted to a data glove worn by the operator, as shown in Figure 2. When combined with stereo vision, as shown in Figure 2, the force feedback can assist in performing skilled work. Stereo vision is achieved with Ovrvision stereo cameras that are placed near the robot and aimed to provide a first person view of the robot's work area. The stereo video signal from the stereo cameras is delivered to an Oculus Rift stereo headset worn by the operator, as shown in Figure. 2. A P5 data glove is used to obtain the coordinates and finger positions of the operator's right hand and used to control the position and orientation of the robot's end effector.

This arrangement can enable the operator to feel immersed in the robot's environment via the stereo perception provided by the Ovrvision stereo cameras and Oculus Rift headset. Also, the proportional force feedback sensation, delivered by the end effector's force sensors and electro-tactile feedback system, enables the operator's right hand to feel as if it is "gloved" or "embodied" into the robot's end effector which can facilitate control and interactions with the environment.

Figure 3 shows an overview of the electro-tactile teleoperation feedback loop. For our local setup, the latency of both the stereo visual feedback system and electro-tactile feedback system is low and therefore requires no synchronization measures.

Figure 1. Robot arm.

Figure 2 .Operator with data glove and the feedback system.

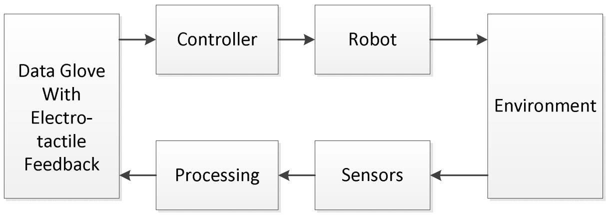

Figure 3. Block diagram of electro-tactile feedback tele-operation system

B. Robot Arm and Sensor

The CRS A465 robotic arm is a 6 DOF arm fitted with a ATI F/T force sensor unit and tool holder, as shown in Figure 1.The ATI F/T force sensor unit can measure six components of force and the torque at the robot's wrist, namely, Fx, Fy, Fz, Tx, Ty and Tz. The tool holder was custom built to fit a grinding/cutting tool or scalpel. To generate electro-tactile feedback signals and transmit the signal to the skin of the operator, the resultant of the force component is used.

The Ovrvision stereo camera was placed above and next to the robot arm to approximate front first person vision of the robot's end effector and work area, as shown in Figure 1. This position makes feel the robot arm feel as it is the user's right arm. This stereo camera is capable of 60fps speed with low latency and has 1280 x 480 pixel resolution. The output of the stereo camera is connected to the Oculus Rift head-mounted stereo display, as shown in Figure 2.

C. Data Glove

A P5 Glove fitted with TENS electrodes was used to control the movement of the robot on local coordinate system and to receive the force feedback, as shown in Figure 4 and 5. This device can give the x,y,z coordinate position of the glove as well as the glove's roll, pitch and yaw orientation. These coordinates are used to move the robot arm using an inverse kinematic algorithm. Furthermore, the bend positions of all fingers can be accessed. Three buttons mounted on the back shell can provide additional signals. To read the glove's position and state, this glove must be placed in front of its receptor tower, as shown in Figure 4.

An electro-tactile feedback receptor unit is attached to the glove's back shell and attached to the TENS electrodes to provide the proportional force feedback stimulus, as shown in Figure 4. The TENS electrodes were fitted to the underside of the glove, as shown in Figure 5. To facilitate conduction, a small amount of conductive gel is applied to the surface of the electrodes.

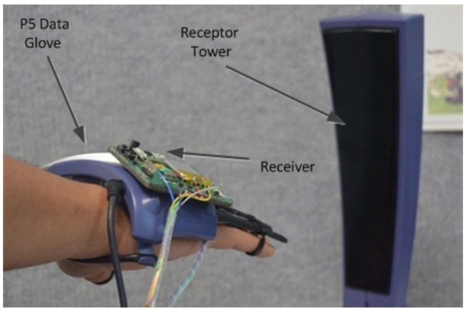

Figure 4. Data Glove with feedback unit and receptor tower

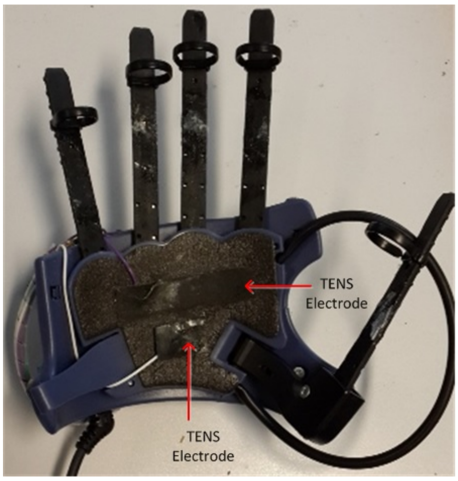

Figure 5. TENS electrodes fitted to data glove

By moving his/her right hand and fingers the operator is able to move the robot arm's end effector along its x, y and z coordinates and twist or bend the robot arm's wrist, with corresponding movements of the glove.

D. *Electro-Tactile Feedback*

The electro-tactile feedback system is comprised of a custom built wireless TENS system, as shown in Figure 6, which is capable of delivering information to the operator's skin electrical pulses. The feedback signal is derived from the resultant magnitude of the robot's force sensors and is used to control the intensity of the stimulus delivered to the skin. Stimulus from the force sensor was calibrate to produce zero stimulus when there was no contact between tool and the object, to intense when the tool was pushing hard again the object.

The feedback electrodes are placed on the centre of the inside of the data glove, so that they make contact with the operator's skin. This arrangement gives the operator variable stimulus via the skin, as explained above. As, the electrodes do not directly stimulate muscles they do not cause the hand to contract. Additionally, the stimulus is relatively mild and does not cause any pain.

The stimulus pulses are set to a frequency at 20Hz. The operator can set the amplitude of the pulses manually before sing the electro-tactile feedback to between 40–80V to suit is or her comfort level. The Intensity is controlled by varying ıe width of the pulse between 10 to 100μs.

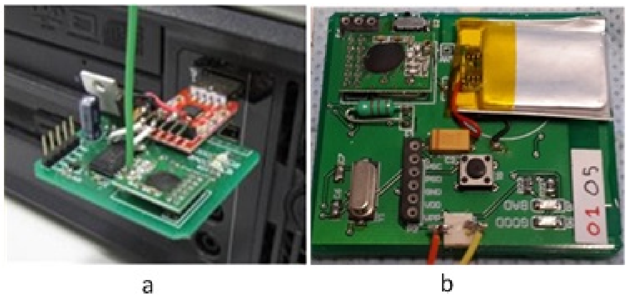

Figure 6. a Feedback transmitter b. TENS receiver unit.

E. *Visual Feedback*

The vision feedback system consists of an OVR stereo camera and an Oculus Rift HMD stereo headset. This stereo camera and headset combination has low latency and is capable of providing the operator with 3D stereoscopic vision, similar to natural vision, with a 100^0 field of view, as shown in Figure 7. Consequently, this can enable the operator to feel as if he/she is immersed in the robot's environment.

IV. Experiment Method

To demonstrate the effectiveness of electro-tactile feedback system two experiments were conducted. For both experiments the robot arm was equipped with a force sensor unit and the operator was equipped with the combined vision-force feedback system described in the previous sections. The first experiment involved controlling the robot to sharpen a knife with a grinder tool-head. The second experiment involved using a scalpel tool head to cut a thin layer of soft dough (only) that is layered on top of a standard sheet of A4 paper glued to balsa wood. The aim of these experiments is to demonstrate that the proposed feedback system can assist an operator to perform skilled tasks that require force/tactile feedback.

A. *Sharpening a Knife*

Sharpening a knife with a hand held cylindrical grinder requires both careful observation of the grinder bit and knife edge while applying the right amount to pressure to the grinding tool. Without adequate visual perception and force and/or tactile feedback, damage to the knife edge and grinder can easily happen. To perform this task via teleoperation with the robot arm and feedback system described in section 3, we fitted the robot arm with a grinder tool equipped with a cylindrical grinder bit, as shown in Figure 8. The knife was held firmly in a vice within reach of the robot arm.

Figure 7. Display stereo camera on computer screen

Prior to attempting this task the operator practices touching some soft objects with the tool head while adjusting the maximum electro-tactile feedback stimulus. This is to obtain appropriate comfortable feedback stimulus relative to the applied tool head pressure. The operator then engages in sharpening the knife a few times with the sound turned on and then again with the sound turned off. We found this task was relatively easy to perform even with the sound turned off. The same task performed without stereo perception and feedback proved very difficult to achieve and took three times longer to accomplish the task.

B. Controlled Cutting

We also conducted experiments cutting various objects with a scalpel fitted to the robot's tool holder. One experiment involved making a controlled cut of a laminate comprised of a layer of soft dough overlaid on a sheet of A4 paper that was glued to a layer of balsa wood, as shown in Figure 9. The laminate was also held firmly to the table with glue.

The objective here is to cut through the dough along a line without cutting into the paper and balsa. Again, this task requires careful monitoring of the tool, the surface and the pressure being applied to the scalpel while making the cut. After calibrating the force feedback stimulus intensity, as described in the previous section, we found that we were also able to perform this task after a number of practice runs with relative ease.

Figure 8. Grinding experiment setup

Figure 9. Cutting Experiment Setup

V. CONCLUSION

An immersive teleoperation system comprised of a robot arm, 3D stereo vision system, an electro-tactile feedback system and a hand gesture based control system is presented in this paper. This feedback system is relatively inexpensive to devise, easy to setup, versatile and avoids complicated mechanical hardware required by most other force/tactile feedback systems. The experimental results show that the proposed electro-tactile feedback system can assist an operator of a robot arm to perform certain tasks requiring a certain degree of skill and force/tactile feedback. For future work, we intend expanding on this work by using the electro-tactile feedback system for more complicated and delicate tasks.

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